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# *The Crew Exploration Vehicle Seat: Seeking a Semi-Custom Fit in an Off-the-Rack World*

## Overview

The CEV, or Crew Exploration Vehicle, was an important component of the proposed five-year, $12-billion "Return to the Moon" Constellation initiative, a new manned space endeavor announced in January 2004 by President George W. Bush.

This revised "vision for space exploration" effort was aimed at shifting NASA's focus from the Space Shuttle and the International Space Station, and their near-Earth-orbit orientation, and back to long-range, manned space missions, in addition to science and hardware maintenance missions in near Earth orbit.

The previous February, the Shuttle Columbia had broken up on return to earth, with the loss of its crew. Under Constellation, NASA looked to retire the remaining three aging Space Shuttles by decade's end, and to conclude the U.S. role in the construction of the Space Station within six years. The eventual goal was to return U.S. astronauts to the moon by the year 2020, and eventually to Mars and beyond.[1]

The CEV was to be a key part of the Orion crew capsule carried atop the new Ares I rocket, which was envisioned as the Space Shuttle's replacement. The launch vehicle was to be made up of a solid rocket booster and main engines derived from the Shuttle. The CEV, which had a launch escape capability for its crew, would be returned to Earth through a ground landing by parachute, a procedure designed for both safety and affordability.[2]

Constellation was slated to conduct its initial manned mission by 2014 at the latest, with missions to the moon tentatively set to start by 2020.[3]

[1] http://www.cnn.com/2004/TECH/space/01/14/bush.space/, "Bush unveils vision for moon and beyond," 1.15.2004.

[2] http://www.associatedcontent.com/article/1924426/nasa_constellation_cev_project_under.html?cat=15

[3] In spring 2010, the Obama Administration indicated it would cancel the Constellation program, and its aim of returning to the moon, and redirect its funds to the development of new space technologies and to taxiing astronauts to orbit aboard commercial space vehicles. http://www.nytimes.com/2010/02/02/science/02nasa.html, Obama Calls for End to NASA's Moon Program, New York Times, 2.2.2010.

## Challenges

Creating a safe, functional, comfortable seat for astronauts in the *Orion* crew exploration vehicle (CEV)—the next lunar explorer—had been a vexing problem for some time. By the end of 2007, engineers at NASA and Lockheed Martin, prime contractor on the project, had been wrestling with the concept and design of a prototype seat for several years.

When the holidays arrived, Dustin Gohmert, an engineer in the Crew and Thermal Systems Division at Johnson Space Center and NASA's team lead, threw himself into what he called "my Christmas project." For two weeks, Gohmert would spend 10-hour days working the problem. With a major benchmark, Preliminary Design Review (PDR), looming on the horizon in 2008, time was critical.

Gohmert and his team had faced some unique challenges. First were the technical hurdles. On the safety side, this meant developing a "seat subsystem" that would allow astronauts to withstand high landing loads, or G-forces, that might be experienced in either land or water landings. Technically speaking, the objective was "to design a simple seat concept that provides full occupant support in all axes for the full range of occupant sizes." But that wasn't the most difficult issue.

As Gohmert said, "Keeping a person safe in a seat that's custom-designed for them isn't hard to do necessarily, but doing it under the constraints where we have one seat that has to fit everyone [without custom components], that was the hard part. And then making it fit inside the vehicle—that's where we stumbled for a while, making those fit together."

*Apollo*, a touchstone for many of the *Constellation* human space flight and *Orion* sub-projects, offered guidance by way of contrast. Where *Apollo* had to accommodate only three astronauts, *Orion* would need to seat six. And in the *Apollo* capsule, the seats were arrayed in a row; in the CEV they would be positioned in a stacked formation—"almost like you're sitting on another guy's head," as Gohmert put it.

"The thing about *Apollo* is that [the pilots] were all [men of] basically the same size. They were all test pilots from the Air Force, so there wasn't a huge variation in sizes….CEV ranges have to be from smaller than a horse jockey to someone as tall as a basketball player, four foot ten to six foot seven"—or, in statistical terms, from the 1st percentile female to the 99th percentile male.

Designing for different sizes and for heights that--stacked together, would have to fit in the CEV--presented an extraordinary engineering challenge. To build a safe, comfortable, adjustable seat would require a "semi-custom" design with some uniquely flexible and user-friendly features. In short, some real innovating. Incorporating human factors—that is, adapting technology to people—was a long way from the "one size fits all" requirements of *Apollo*, when people were fitted to the technology.

The CEV seat project had encountered another challenge. The requirements had been written before the technology and issues were fully understood. The individual components of the mission hardware were designed before the crafting of an overarching program plan. This was akin to placing the cart before the horse. When the program plan was written, it ran the risk of being inconsistent with components that had already been designed and built.

Lockheed Martin had fulfilled the terms of its contract, strictly speaking. But the project as a whole proceeded without clear requirements. "In a sense," said Gohmert, "it wasn't [the contractors'] fault they couldn't do what we were asking them to do. It was kind of like saying 'Bring us a rock,' and when they did, saying, 'That's not the kind of rock we wanted'."

A related problem was that the program proceeded under the philosophy of "parallel development". This meant that individual, separate facets of the program were developed at the same time, instead of sequentially, in a spiral development process, which takes place in a more measured, step by step way.[4] The potential benefit of parallel development was faster development. The potential risk was that one facet wouldn't "fit" with another facet. Fixing such a problem could entail considerable time and expense, because both facets would have been already completed.

Which is how Gohmert, an amateur carpenter who grew up on a ranch in Texas "fixing things," found himself spending long days in his garage from Christmas 2007 through New Year's Day 2008, building a seat prototype for the *Orion* crew exploration vehicle.

## The Requirements

The design problem could be broken out into specific technical challenges: the "Leg Curvature Problem" ("flat seats are flat, humans are not"), the "Leg Length Differences Problem ("we have to accommodate varying thigh and lower leg lengths, but the seat and IML (inside mold line) do not move"), and so on.

Six basic requirements and needs were identified:

- Occupant protection (e.g., conformal support, load-distributing harness)
- Adjustable fit for all sizes
- Stowability
- Multipurpose (for both operator and non-operator seats)
- Reliable (technologies and materials proven for spaceflight)
- Lightweight

In his search for innovative design solutions, Gohmert tapped a variety of sources.

## From Space Shuttle to Monster Trucks and NASCAR: Drawing on Ideas from the Outside

Gohmert's experience included work on the Space Shuttle's Advanced Crew Escape Suit, or ACES[5]. This helped him understand the interface between the suit and chair, a critical element, relative to the first two of the requirements in particular. Unique hardware features, such as air supply lines, pressure controllers, emergency oxygen bottles, and survival gear, demanded special considerations to integrate the suit with the seat. The challenge: CEV seat and spacesuit had to function as an integrated unit.

As Gohmert explained, "A spacesuit has many more considerations for functionality than a normally clothed person or even a person in special protective clothing, such as a NASCAR or Indy car driver."

Understanding, for example, how helmet interaction with the seat differed from the design and functionality of, say, NASCAR drivers' helmets, which Gohmert actually studied, would lead to creation of a single adjustment point for headrest, shoulder supports, and harness. Earthbound vehicles were, in fact, a primary source of innovation ideas for Gohmert and his team in the conceptualization, design, and prototyping of a CEV seat that would address both the unique crew size/vehicle-space problems and the seat–suit integration issues.

[4] CEV: The Last Battlestar? http://www.spacedaily.com/news/oped-05zl.html,

One of the problems with an early seat concept was that its square design didn't address the issue of having to constrain side-to-side motion. From lessons learned in the racing industry, the CEV-seat team knew that every part of the body should stop at the same time, and there should be little free motion in any direction. ("In a +Z impact, the body is going to find those empty spaces and fill them"). Gohmert set out to design a seat in which the curved area at the buttocks was adjustable for different leg lengths, and where spacers of different sizes could be fitted between the suited astronauts and the outer edges of the seat.

The engineer and his team had also discovered an unlikely similarity between their requirements and another unique vehicle: monster trucks. As he described it, "In the monster truck world, the repeated loads [18 Gs, comparable to the worst loads astronauts might experience], are almost identical to what we're looking at in CEV… so we took lessons from restraint systems they use."

*Figure 1 - Monster Truck. NASA engineers looked to the prosaic world of "monster trucks" to conduct research on seats designed for potentially rough –and-tumble settings. Credits: Jot Powers, 1/2006.*

The proverbial light bulb went off at a meeting with NASCAR representatives. Gohmert described the process:

> *I was sitting in a big meeting we were having in December 2007 and watching all kind of presentations from NASCAR guys. They were showing their custom conformal seats, but all of us who were CEV-seat savvy knew they would not work for us in that incarnation. But then I had an idea of how to take their underlying principles of protection and make them work for us without having to re-invent the CEV. So I drew it on the back of the meeting itinerary and saved it so I would not forget. The actual design concept was pretty much conceived in a matter of minutes during that meeting, but was predicated on years of study that just seemed to click.*

In the course of the project, Gohmert had made little headway pitching ideas for reconceived seat components—"Everybody has sketches"—and he had developed a measure of skepticism about the flexibility of computer modeling prototypes. So for the new design he undertook an old-fashioned, hands-on approach. After a stop at a building supplies store, with materials and a few new tools in hand, he began bringing the concept to life:

"The whole design was done on a big piece of cardboard on my living room floor, where I drew lines and tangents and intersections based on our human measurements specifications, along with our vehicle dimension limitations.

"I used traces of my own body posture," he noted diplomatically, "to help resolve shapes such as the contour of the seat pan."

**The Prototype Emerges**

From the living room he headed to the garage. There Gohmert made what he called "an accidental discovery." After constructing the prototype, he'd discovered that people's hands ended up near their knees regardless of size differences. "I was calling for my fiancé to come get the camera to take a picture of me sitting in the seat," he said. "While I sat there I realized that my hands were sitting on the leg supports in a very natural posture. Then it just made sense to explore putting the hand controllers there." The knee area turned out to be an ideal place to put controllers for the flight crew.

It was a breakthrough. "This was a fortunate discovery, because the placement of the hand controllers had been vexing us for some time. The alternative is a cantilevered arm-rest that protruded from the seat frame. This was never really liked by the team because it was always in the way and impeded egress. It was potentially weak and unstable, since it was a cantilevered beam floating in space.

*Figure 2 - Evolution of the CEV Seat Prototype in Dustin Gohmert's Garage, Early Stage. Image Courtesy of Dustin Gohmert.*

*Figure 3 - Evolution of the CEV Seat Prototype in Dustin Gohmert's Garage, Later Stage. Image Courtesy of Dustin Gohmert.*

"I was a little frustrated, because I thought I was through building on the seat when I discovered that. I knew I was gonna have to tear it apart and rebuild that part to accommodate the hand controllers." After confirming that the configuration wasn't a "unique anomaly" by summoning neighbors to serve for seat fittings in the model, Gohmert went back to work, adding the feature to the design.The design innovations and physical modeling of the CEV seat prototype evolved out of the collaborative process, said Gohmert. "This is an upgrade of your design," he told his partners at Lockheed Martin. "Everything we learned culminated, and finally it just all fit together."

After emerging from Gohmert's garage, the team further refined the seat prototype. "The improvements were to the betterment of it," he said. "We worked as a team to expand on it. Really, the entire seat was never a whole new concept, but an expansion of what [Lockheed] started with. It was just taking it to the next level." By drawing on outside ideas, they had something to work with. From that, they built a prototype.

## Tips and Traps on the Road to Innovation

Dustin Gohmert was quick to point out that his experience innovating a new seat design for the *Orion* CEV was an "exercise in integration, a collaborative process with Lockheed Martin"--the contractor responsible for delivering the final product.

He credited an open work environment for innovation breakthroughs: "I was able to do this because of opportunities I have within NASA to think outside the box. Additionally, I have had learning opportunities that I was able to draw upon that not everyone has been fortunate enough to experience."

Based on his experience with the CEV seat project, Gohmert drew up some tips for how to innovate successfully—and how to prevent pitfalls. This is the essence, in his words, of what he learned:

> *Make a list of requirements--not in the legalese version written in our requirements' documents, but in plain English as they apply to you. Take that and really understand what that means to the design. Let form follow the function needed…. "I was close-minded for a long time, because it was not clear how much load protection we needed. Once I started to accept that more occupant protection was needed, [I had] more creative thought….. "I am bullheaded myself and am resistant to changing my opinion. But there are lots of smart folks with lots of good ideas. The trick is to take the parts of those good ideas you can use and be smart enough to work around other limitations they present."*
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> *"[Computer models are useful tools, but have severe limitations. For example, computer models of people project them as rigid objects that do not form or mold to their surroundings. We are in fact soft and squishy, and we have a great deal of adaptability. By stepping away from what the models and measurements blindly predicted, we were able to consider more creative and comfortable postures and solutions."*
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> *"I try to make it very clear that this seat and the seat we will have in Orion is ours as a team, not mine. I had a concept that set us on a path and a clear vision on how I would like to aid us along the path, but I know that these guys on our team, who are picking materials and analyzing stiffness, and strength, and factors of safety, etc., deserve the real credit….*

## Design and Test

In the months following Gohmert's "Christmas project," development of the CEV seat followed a methodical course:

1. Computer-Aided Design (CAD) modeling of design to optimize seat stowability
2. Refinement and development of design concept with Lockheed Martin and NASA Engineering Safety Center (NESC) teams
3. Analysis from occupant protection experts
4. Design and development of functional sliding/locking mechanisms

5. Human factor evaluation of a full range of postures, suited and unsuited
6. Mannequin-sled testing to evaluate concepts with different size subjects

After completing two weeks of acceleration-sled testing, a "trial-and-error improvement" process, at Wright Patterson Air Force Base in Ohio, the CEV seat prototype was being prepared for production by Lockheed Martin.

**Additional Resources**


- Web site, Crew Exploration Vehicle, FAQ: http://www.nasa.gov/missions/solarsystem/cev_faq.html
- "Crashworthy Seats Would Afford Superior Protection," Lyndon B. Johnson Space Center, Friday, May 01, 2009: http://www.techbriefs.com/component/content/araticle/5245